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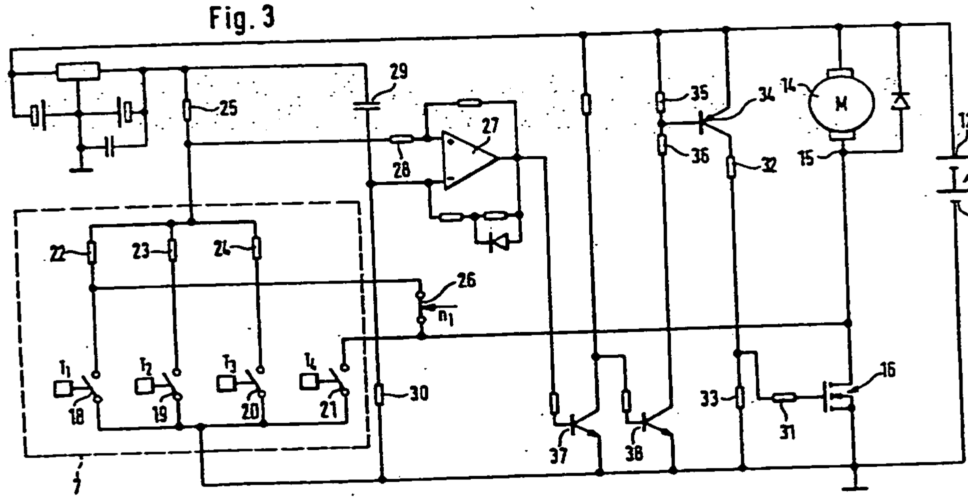
(54) Cooling system for an internal combustion engine

(57) The speed of the electric motor 14 driving a cooling fan or water pump of an i.c. engine is influenced by means of a power semiconductor 16 triggered depending on the coolant temperature detected by a sensor (not shown). At least three switching contacts 18, 19, 20, 21, are provided each of which is actuated when an associated specific temperature threshold T1, T2, T3, T4 is reached. The contact 21 for the highest temperature threshold bridges the power semiconductor 16. The other contacts 18, 19, 20 for lower temperatures are connected to an input of an operational amplifier 27 via resistors 22, 23, 24, the output of the amplifier 27 being connected via transistors 37, 38, 34 to the gate of power semiconductor 16. A thermistor may be used to provide a proportional characteristic over part of the temperature range.

Fig. 3



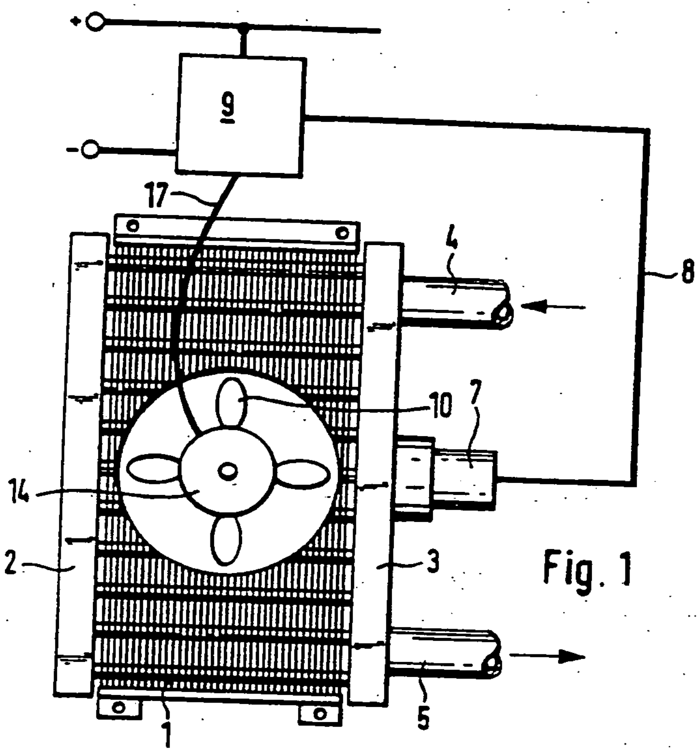

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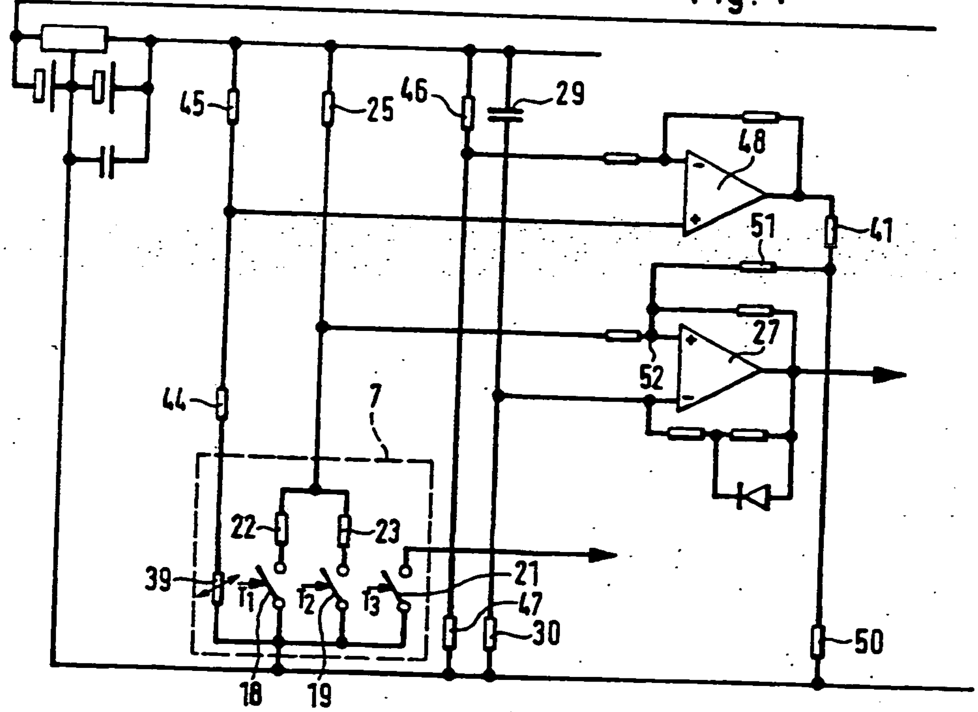
Fig. 1

Fig. 4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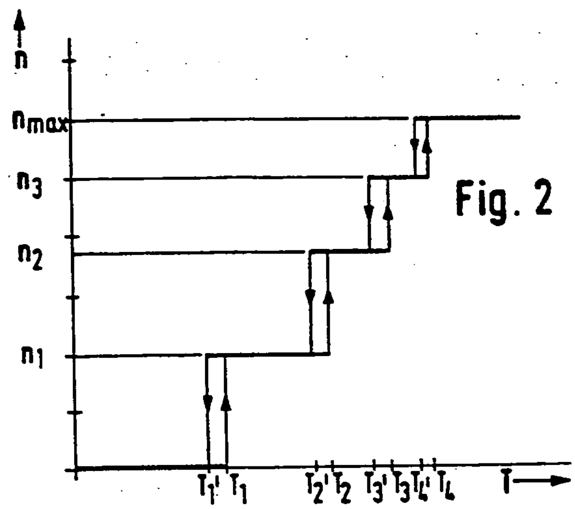

Fig. 2

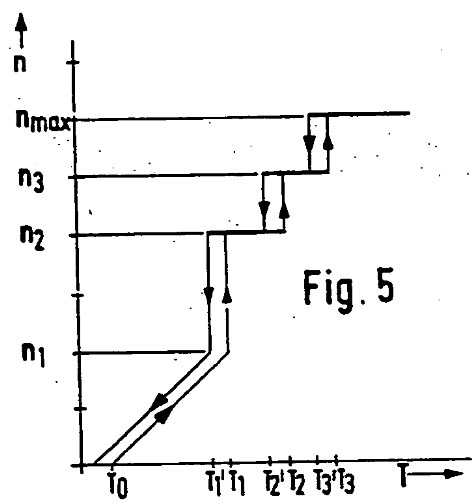

Fig. 5

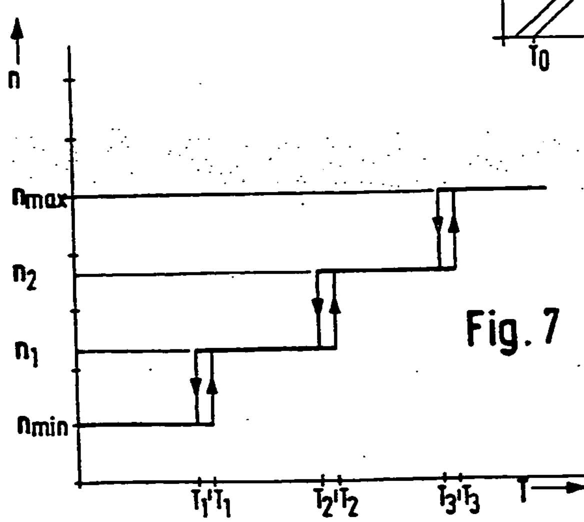

Fig. 7

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Fig. 3

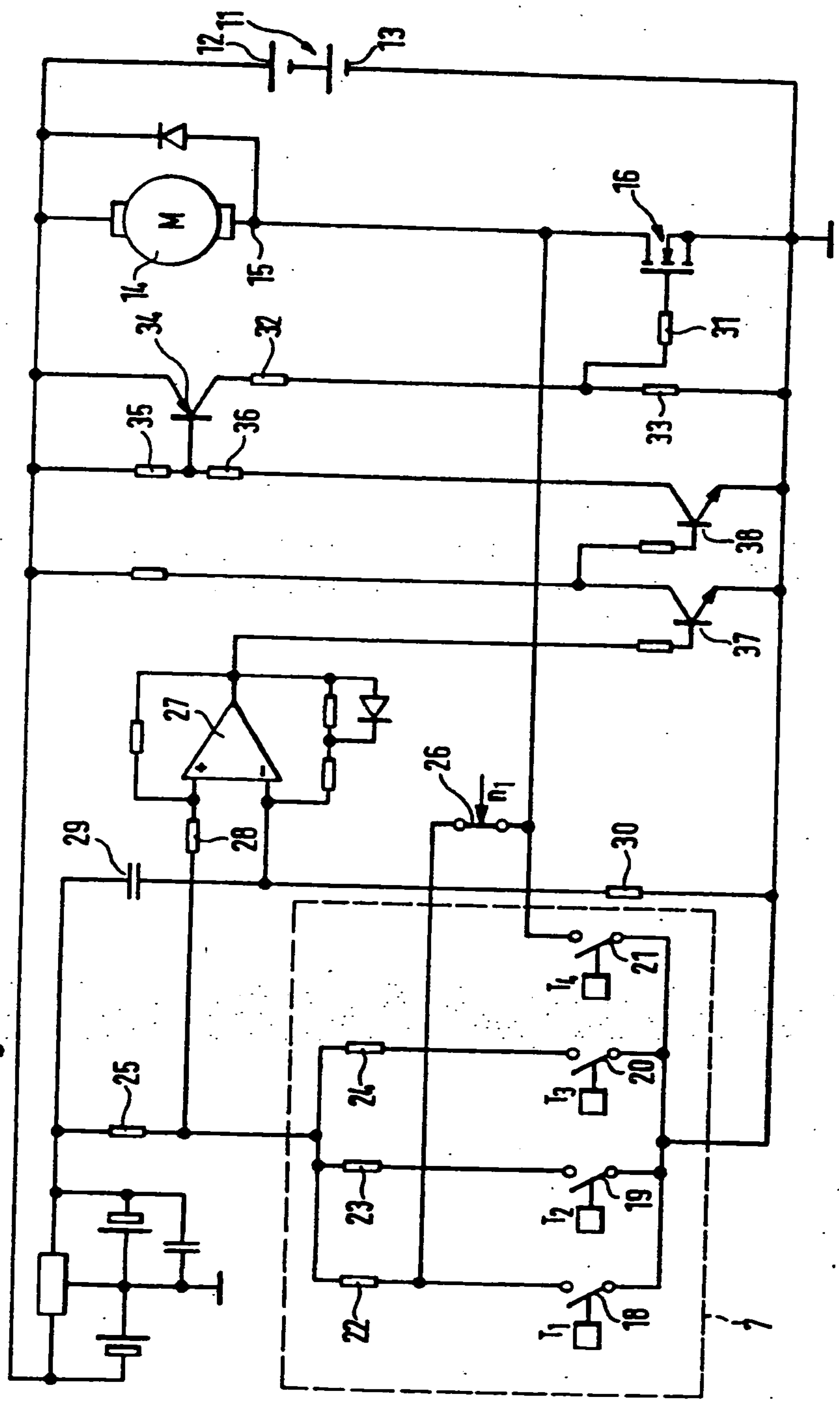


Fig. 6

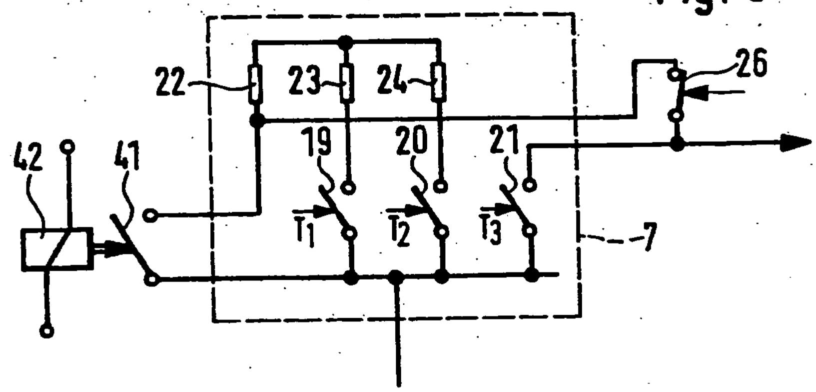


Fig. 8

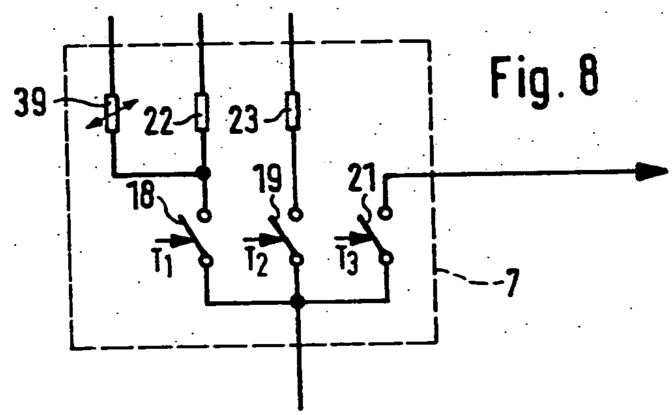
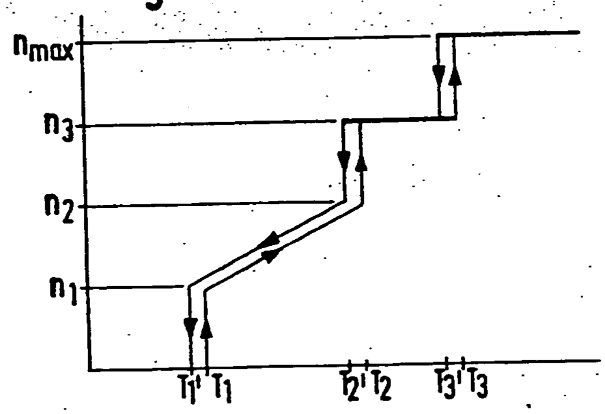


Fig. 9



Cooling System for an internal combustion engine and method of controlling such a cooling system

The invention relates to a cooling system for an internal combustion engine, particularly but not exclusively of a motor vehicle, comprising a heat exchanger, a cooling water pump and a cooling fan for conveying the cooling air through the heat exchanger and also an electric motor for driving the fan or cooling water pump, the speed of the electric motor being influenced by means of a power semiconductor connected to the motor circuit of the electric motor.

A device for regulating the temperature of a cooling system of an internal combustion engine, particularly for motor vehicles, is known from German Patent Specification 28 06 708. This device comprises a coolant circuit which connects the engine to a heat exchanger, the circulation of the coolant being effected by a cooling water pump of the engine. In addition, it comprises a blower system which has at least two blower units for the heat exchanger which can be operated in at least two power ranges which are independent of the engine speed. Moreover, this device comprises a plurality of temperature switches which are arranged at different measuring points and associated with specific temperature thresholds. When a first temperature threshold is exceeded, the blower motors are operated at a mean speed and when a second temperature threshold is exceeded, they are operated at the maximum speed.

However, the disadvantage of such a device is that two complete blowers (fan and motor) are required and that the blowers can only be operated at two different speeds. In this way the different temperature ranges occurring in a cooling system can only be taken into account to an insufficient degree. Moreover, with such devices the use of the maximum blower speed becomes necessary frequently

so that the blower noise which is found to be troublesome at maximum speed occurs with relative frequency.

A switching circuit for an electric drive motor of a fan for a radiator of an internal combustion engine of a motor vehicle is known from European Patent Application 0 054 476, the electric motor being triggered depending on the temperature of the cooling water in each case. At the same time the speed of the electric motor can be influenced by means of a power semiconductor which is triggered by way of an electronic circuit depending on the signal from a temperature sensor. In addition there is provided a relay, the switch contact of which is connected in parallel to the power semiconductor and bridges the semiconductor in specific operating conditions. The relay is part of a safety circuit designed in such a way that the relay is activated if the triggering of the power transistor corresponds to continuous duty. In addition the relay is switched on if the temperature sensor fails. Indeed, the known circuit has the advantage that continuous control of the speed of the electric motor or fan is possible, but an expensive triggering system or the use of very powerful and thus costly semiconductors is necessary for this purpose.

It is imprudent to operate the power transistor with a relative duty cycle of more than 95% because the pulsed current power dissipation, particularly of metal oxide power transistors, is three to four times greater than during continuous duty. Moreover, a specific voltage always drops because of the resistance between the drain and source terminals on the power transistor so that in the event of relative continuous duty of the power transistor, it is necessary to achieve a speed distinctly less than the nominal speed.

The problem for the present invention is therefore to create a cooling system for an internal combustion engine of the type specified in the opening paragraph with which a simple control circuit constructed from relatively

cheap components enables speed regulation of the electric motor adapted to different temperature levels of the cooling circuit and with which operation of the drive motor via the power semiconductor in specific unfavorable speed ranges is avoided. There is also the additional problem of developing a method of controlling a cooling system of this type.

According to the present invention there is provided a cooling system for an internal combustion engine, comprising a heat exchanger, a cooling water pump and a cooling fan for conveying the cooling air through the heat exchanger and also an electric motor for driving the fan and/or cooling water pump, the speed of the electric motor being influenced by means of a power semiconductor connected to the motor circuit of the electric motor and the power semiconductor being triggered depending on at least one sensor which detects the coolant temperature or an adequate value, wherein there are provided at least three switching contacts, each of which is actuated when an associated specific temperature threshold is reached, the contact for the highest temperature threshold bridging the power semiconductor and the other contacts being connected to an input of an operational amplifier by interposing electronic components, the electronic components influencing the input parameters of the operational amplifier in such a manner that there is a specific output signal of the operational amplifier relating to the operating point of each of these contacts.

The essential advantages of the invention can be seen in that only a small circuit design effort is required to control the motor speed and despite this the electric motor can be operated at a number of different speeds.

The problem of developing a method for controlling a cooling system of this type is solved in accordance with the invention is that switch contacts are closed successively by means of the temperature-sensitive sensor

when preset switching thresholds are reached, whereby the input parameter is varied at a non-inverting input of an operational amplified and the output level of the amplifier is varied, and that as a result of the varied output level of the operational amplifier, the power semiconductor is triggered in such a manner that the electric motor is operated at specific speeds associated with steps of respective switching thresholds, and that the power semiconductor is bridged when the last switch contact is closed.

An advantageous development of the invention is that the electronic components which influence the input parameters are ohmic resistors. In this way the circuit arrangement can be simply adapted to suit any desired cooling system because only the ohmic resistors associated with the switch contacts need to be designed accordingly to determine the timing frequency and thus also the speed stages.

For the purpose of the integration of components it is proposed that the switch contacts be arranged jointly in a step switch. An expanding material element which interacts with the step switch is suitable and preferred for the temperature sensor. In such a case it is advantageous that the step switch is arranged on the water box of the heat exchange and the expanding material element projects into the water box so that the stream of cooling water washes around the element.

The power semiconductor is preferably an N-channel metal-oxide field effect transistor and the operational amplifier is a voltage-controlled frequency generator. In order to apply a suitable control voltage to the gate of the metal-oxide field effect transistor, a switching transistor is connected between a positive pole of the voltage source and the gate of the metal-oxide field effect transistor, the base of the switching transistor being connected to the output of the frequency generator via two inverting switch steps.

Because the starting currents of high-powered electric motors are great, a speed control which is to begin with very low speeds can only be accomplished by parallel connection of powerful semiconductors. Because of the effect of back electromotive force current consumption drops, when reaching a specific speed, into a range in which lower powered semiconductors can be used. For this reason an advantageous development of the invention consists in providing a switch contact which opens subject to the speed of the electric motor and which is arranged after the first closing switch contact in the circuit and bridges the power semiconductor until a first speed stage is reached. In this way it is ensured that the electric motor does not have to be started by the power semiconductor and the semiconductor is protected from the high starting currents occurring at the same time so that it is operated only in a working range in which the load does not assume extreme values. Moreover, the electric motor has the full voltage at its disposal for starting so that a high torque is achieved.

A further development of the invention is that a closing contact of a relay and a resistor are provided in a line branch which is connected to the resistors in parallel with the switching contacts and the relay coil is triggered by a signal which is dependent on a specific speed of the internal combustion engine or a voltage of the generator. This design is particularly meaningful if the electric motor drives the coolant pump. This ensures that, when the internal combustion engine is stationary, the coolant pump is not operated and thus all the energy is available for the starting operation, and that moreover a minimum speed of the coolant pump is ensured during operation of the internal combustion engine.

In order to achieve a control characteristic of the electric motor or blower driven by this electric motor whereby a continuous proportional increase in speed is effected within a specific range of coolant temperatures

and the speed increase is to be effected in stages outside this temperature range, it is proposed that a temperature sensor be provided in the form of a thermistor which is connected to the non-inverting input of a second operational amplifier via a potential divider and the output of which is connected to the non-inverting input of the first operational amplifier.

In order to keep the necessary connecting lines as short as possible, it is advantageous to assemble the control electronics, at least in so far as they comprise the power semiconductor and operational amplifier, into a modular unit and to arrange this unit directly on the electric motor, that is on the side of the motor remote from the fan. As a result, the unit is situated in a place hardly exposed to dirt and does not generate an additional flow resistance to the fan air stream.

Embodiments of the cooling system according to the invention will now be described in detail below by way of example with the aid of the drawings.

In the drawings:

Fig. 1 shows a diagrammatic view of a cooling system,

Fig. 2 shows a control characteristic,

Fig. 3 shows a connection diagram of an electric control circuit for a radiator fan of a motor vehicle,

Fig. 4 shows a modified embodiment of the temperature-dependent switch contacts in combination with a parallel-connected temperature sensor,

Fig. 5 shows a control characteristic which is achieved with the embodiment according to Fig. 4

Fig. 6 shows a modified embodiment of the temperature-dependent switch contacts which is particularly suitable for the operation of a coolant pump,

Fig. 7 shows a control characteristic which is achieved with a circuit according to Fig. 6

Fig. 8 shows a modified embodiment of the temperature-dependent switch contacts according to Fig. 4

having a thermistor, and

Fig. 9 shows a control characteristic which is achieved with the circuit arrangement according to Fig. 8

A cooling system essentially comprising a heat exchanger 1 with lateral water tanks 2 and 3, and also a radiator fan 10 driven by an electric motor 14 is shown diagrammatically in Fig. 1. A coolant inlet pipe 4 and a coolant return pipe 5 are provided on the water tank 3. Also arranged on the water tank 3 is a switching unit 7 which will be explained in detail below with reference to Figs. 3, 4 and 6. The switching unit 7, which is actuated by a temperature-controlled working element, for example an expanding material element, is connected to an electronic unit 9 via a connecting cable 8. A connecting cable 17 leads from the electronic unit 9 to the electric motor 14 which drives the fan 10.

In the view according to Figure 2 the speed n of the fan motor is plotted over the temperature T of the cooling water. In the case of this control characteristic the fan motor is in a stationary position until a temperature value T1 is reached. When a first temperature threshold at T1 is reached, the fan motor is switched on and brought to a speed n1.

With the temperature rising, the motor speed n1 is maintained until a second temperature threshold at T2 is reached. When this second temperature threshold T2 is reached, the fan motor is brought to a second speed stage n2, the motor maintaining this speed until the next temperature threshold at T3 is reached. If this temperature is reached the fan motor is operated at speed n3. The next switching threshold is reached at a temperature of T4 at which the fan speed is raised from n3 to n max. When the temperature of the cooling water drops, i.e. even when there is a decrease in temperature before the last temperature threshold at T4 is reached, the speed is reduced in stages n3, n2 and n1 in accordance with the control characteristic, the reduction taking

place at each of the temperature thresholds T4', T3', T2' and T1' as a result of the hysteresis normally inherent in the switching elements.

Fig. 3 shows a voltage source 11 in the form of a battery of a motor vehicle, the positive pole 12 and negative pole 13 of which are connected to the electric motor 14. A metal-oxide field effect transistor 16, hereinafter called MOSFET, is inserted into the connecting line between the negative terminal 15 of the motor 14 and the negative pole 13 of the voltage source 11. The control circuit also comprises a switching unit 7 consisting of a step switch having four switch contacts, 18, 19, 20 and 21. The step switch is constructed in such a manner that the switch contacts 18, 19, 20, 21 are closed successively, that is when each of the preset temperature values T1, T2, T3, T4 is reached.

The switching unit 7 comprises three resistors 22, 23 and 24, each resistor in parallel line branches being associated with respective switch contacts 18, 19 and 20. The ends of the resistors 22, 23 and 24 remote from the switch contacts 18, 19 and 20 are short-circuited by means of a bridge and combine with a resistor 25 to form a potential divider between the positive and negative terminals of a stabilized voltage.

A connecting line leads from the switching contact 21 to the negative terminal 15 of the electric motor 14. There is also provided a speed-controlled opening contact 26, which, on one side, is connected to the switch contact 18, and on the other side, connected to the negative terminal 15 of the electric motor 14. The opening contact 26 is opened when a preset speed stage n1 of the electric motor 14 is reached.

The non-inverting input of an operational amplifier 27 is connected via a resistor 28 to the potential divider which consists of the resistors 25 and 22, 23, 24. The inverting input is connected to an RC-network comprising a capacitor 29 and an ohmic resistor 30.

The gate of the MOSFET 16 is connected via a resistor 31 to a potential divider comprising resistors 32 and 33. Between the resistor 32 and the positive pole 12 of the voltage source 11 there is a switching transistor 34, the base of which is connected to a potential divider formed by resistors 35 and 36. The resistor 36 is connected to the output of the operational amplifier 27 via two inverting stages 37 and 38 in the form of n-p-n transistors.

The mode of operation of the radiator fan 10 in Fig. 1 is described below with the aid of the control characteristic shown in Fig. 2 and the circuit shown in Fig. 3. As long as the temperature of the cooling water lies below a first temperature threshold, all the switch contacts 18, 19, 20 and 21 are open so that the negative terminal 15 of the electric motor 14 is not connected to the negative potential of the voltage source 11. The electric motor 4 is consequently stationary.

When a first temperature threshold T1 is reached, the switch contact 18 is closed as a result of which the negative terminal 15 of the electric motor 14 is connected to the negative potential of the voltage source 11 via the opening contact 26 and the switch contact 18. This causes the electric motor 14 to start until it has reached a first speed stage n1. With the closure of the switch contact 18 a change in the input parameter also takes place at the non-inverting input of the operational amplifier 27 by way of the resistor 22, the output of the operation amplifier generating a pulse train which is applied to the base of the switching transistor 34 via the two inverting stages 37 and 38. In accordance with the pulse train the gate of the MOSFET 16 is also triggered resulting in a relative duty cycle of the electric motor 14 which corresponds to the first speed stage n1. Because the opening contact 26 is opened upon the first speed stage n1 being reached, the electric power is subsequently fed to the electric motor 14 only through the MOSFET 16.

Upon a further increase in temperature the speed of the electric motor 14 is maintained until a second temperature threshold T2 of the cooling water is exceeded. The contact 19 in the switching unit 7 is then closed, which results in a reduction of the joint resistance of the parallel connection comprising the resistors 22 and 23. This causes a change in the input parameter of the non-inverting input of the operation amplifier 27 whereby the pulse train at the output of the operation amplifier 27 is influenced in such a manner that a higher duty cycle of the MOSFET 16 is obtained. Because of the higher duty cycle the electric motor 14 or the radiator fan 10 driven by this motor is now operated at a second speed stage n2.

A further increase in the speed of the electric motor 14 only takes place when a third temperature threshold T3 is exceeded, whereupon the switch contact 20 in the switching unit 7 is closed. Upon the highest temperature threshold T4 being exceeded, the switch contact 21 is closed whereby the MOSFET 16 is bridged. By being bridged the load is removed from the MOSFET 16, which has the advantage that it is not exposed to a peak load and the electric motor 14 reaches its maximum speed which could not be achieved even when the MOSFET 16 is triggered with a continuous duty cycle.

When the temperature of the cooling water falls, the switch contacts 18 to 21 in the switching unit 7 are opened again the inverse order as a result of which stepwise reduction in the speed of the radiator fan takes place.

Fig. 4 shows a modified embodiment of the temperature-dependent switch contacts and the operation amplifier which can be used instead of the switching unit 7 and the following amplifier unit in the circuit in Fig. 3. The switching unit 7 has three switch contacts 18, 19 and 21 in parallel connection, the switch contact 18 being closed at a first preset temperature T1 and the second switch contact 19 being closed at a second predetermined

temperature T2. Resistors 22 and 23 are arranged after the switch contacts 18 and 19. The switch contact 21 corresponds to that described in Fig. 3 and it has the same function, namely to bridge the MOSFET 16 when the highest temperature threshold T3 is reached. Just as in Fig. 3 the resistors 22 and 23 combine with a resistor 25 to form a potential divider to which the non-inverting input of the operation amplifier 27 os connected. Also, the connection between the inverting input and the RC-network is identical to Fig. 3.

The switching unit 7 in Fig. 4 also comprises a thermistor 39 which is in series with a potential divider consisting of ohmic resistors 44 and 45. A second operational amplifier 48 is connected by its non-inverting input to the potential divider (resistors 44, 45) and by its inverting input to a second potential divider comprising resistors 46 and 47. The output of the second operational amplifier 48 is connected to the negative potential via another potential divider comprising resistors 49 and 50. By way of a dropping resistor 51 connected to the potential divider (resistors 49, 50), the output of the second operational amplifier 48 is connected to a connecting point 52 at the non-inverting input of the operational amplifier 27.

Fig. 5 shows a control characteristic which is achieved with the circuit embodiment according to Fig. 4 and with an electric control circuit corresponding otherwise to Fig. 3. As can be seen from Fig. 5, it is already possible to detect at a relatively low temperature To an influence on the variable resistor 39 whereby the input parameter at the non-inverting input of the second operational amplifier 48 is influenced. At the output of the second operational amplifier 48 a signal is thus generated, which is transmitted to the connection point 52 via the resistors 49 and 51 and consequently added to the voltage at the non-inverting input of the operation amplifier 27. The amplification factor and thus the rise

in the characteristic curve can be influence in the customary manner by the design of the input and regenerative resistors. In accordance with the output signal at the operation amplifier 27 the gate of the MOSFET16 is triggered and the electric motor 14 begins to rotate. As the temperature of the cooling water rises, a continuous increase in the fan speed is caused because the duty cycle factor of the MOSFET 16 is increased correspondingly.

When the already mentioned temperature threshold T1 is reached, the switch contact 18 then closes whereby the input voltage at the operation amplifier 27 is changed significantly. The voltage applied to the connection point 52 by the potential divider of the resistors 22 and 25 now has a dominant influence on the operational amplifier 27; the voltage component delivered by the output of the second operational amplifier 48 via the resistors 49 and 51 becomes negligible because of this influence. This results in the speed of the electric motor 14 being increased from a first speed stage n1, which was reached before closure of the contact 18, to a second speed stage n2. The same process is repeated upon higher temperature thresholds being reached at T2 and T3 as shown in Fig. 5.

Fig. 6 shows a modified embodiment of the switching unit 7 in Fig. 3 and which can be used for example in the control circuit shown in Fig. 3. The reference numerals from Fig. 3 have been adopted for essentially identical components. In the view according to Fig. 6 there is provided a relay 42 which switches a relay contact 41. The relay contact 41 is in parallel connection with the temperature-dependent controlled switch contacts 19 and 20 and is followed in the circuit by a resistor 22 which is in parallel connection with the resistors 23 and 24. As in Fig. 3, there is also provided a speed-dependent controlled opening contact 26 which is connected to the relay contact 41. The coil of the relay 42 is triggered

for example in such a manner that, at the moment at which the generator of a vehicle delivers sufficient potential, for example upon the idling speed of the internal combustion engine being reached, the coil is excited. When the internal combustion engine is switched off - or even stalled - the relay 42 is released again. Unlike the unit in fig. 3, the switching unit 7 merely has three switch contacts 19, 20 and 21, and the first speed stage n1 is reached via the external relay contact 41.

The control characteristic which is achieved with a control circuit according to Fig. 6 is shown in Fig. 7. In order that the full electric power may be available for the starter when the internal combustion engine is started, the coil of the relay 42 is at first not energised. Therefore the relay contact 41 is opened. Because the switch contacts 19, 20 and 21 of the switching unit 7, for example of a step switch, are also opened, no voltage is applied to the electric motor 14 so that the latter is stationary. After the starting operation of the internal combustion engine, i.e. after the idling speed is reached, the generator delivers a voltage whereby the coil of the relay 42 is energised and the relay contact 41 is closed. The input voltage of the operational amplifier 27 is now changed by way of the resistor 22 in the manner already described so that a minimum speed n min is established in the electric motor 14. To facilitate starting of the motor there is provided the switch contact 26, the function of which has already been described in Fig. 3.

Upon a first temperature threshold T1 being reached, the switch contact 18 is closed in the manner already described with reference to Fig. 3 whereby the gate of the MOSFET 16 is triggered by means of a pulse train transmitted by the operation amplifier 27. The speed control thus corresponds essentially to that already described in Fig. 3, but with the difference that a minimum speed n min of the electric motor 14 is

established instantly. Such a control characteristic is particularly advantageous for driving coolant pumps because a minimum flow rate of cooling water through the internal combustion engine must be ensured.

The difference between Fig. 4 and Fig. 8 is that the thermistor 39 is not in parallel connection with the switch contact 18, but is arranged after this switch contact in the circuit. Otherwise the circuits are the same with regard to the two operation amplifiers 27 and 48. The resistor 23 is to be dimensioned in such a way that with the switch contact 19 closed, the change in resistance of the thermistor 39 is unimportant to the pulse train signal for triggering the MOSFET 16.

The control characteristic which is achieved with a circuit according to Fig. 8 is shown in Fig. 9. It can be seen from this view that, in contrast to Fig. 5, the section with the continuous speed control lies not below the first speed stage n1, but between the speed stages n1 and n2.

Only a few embodiments are described above, but a number of combinations and suitable modifications of these embodiments are conceivable. These can be simply achieved by appropriate adaption of circuitry means which are suitable for control systems of this type.

Claims

1. Cooling system for an internal combustion engine, comprising a heat exchanger, a cooling water pump and a cooling fan for conveying the cooling air through the heat exchanger and also an electric motor for driving the fan and/or cooling water pump, the speed of the electric motor being influenced by means of a power semiconductor connected to the motor circuit of the electric motor and the power semiconductor being triggered depending on at least one sensor which detects the coolant temperature or an adequate value, wherein there are provided at least three switching contacts, each of which is actuated when an associated specific temperature threshold is reached, the contact for the highest temperature threshold bridging the power semiconductor and the other contacts being connected to an input of an operational amplifier by interposing electronic components, the electronic components influencing the input parameters of the operational amplifier in such a manner that there is a specific output signal of the operational amplifier relating to the operating point of each of these contacts.

2. Cooling system according to claim 1, wherein the electronic components which influence the input parameters are ohmic resistors.

3. Cooling system according to claim 1 or 2, wherein a plurality of switching contacts are arranged jointly in a step switch.

4. Cooling system according to claim 3, wherein an expanding material element is provided as the temperature sensor and interacts with the step switch.

5. Cooling system according to claim 4, wherein the step switch is arranged on the water tank of the heat exchanger and the expanding material element projects into the water tank so that the cooling water washes around the element.

6. Cooling system according to claim 1, wherein the power semiconductor is an N-channel metal oxide field effect transistor and the operational amplifier is a voltage-controlled frequency generator.

7. Cooling system according to claim 6 wherein a switching transistor is connected between a positive pole of the voltage source and the gate of the metal oxide field effect transistor, the base of the switching transistor being connected to the output of the frequency generator via two inverting switch steps.

8. Cooling systems according to any one of the preceding claims, wherein there is provided a switching contact which opens depending on the speed of the electric motor and which is arranged after the first closing switching contact in the circuit and bridges the power semiconductor until a first speed stage is reached.

9. Cooling system according to any one of claims 1 to 8, wherein a closing contact of a relay and a resistor are provided in a line branch which is connected to the resistors in parallel with the switching contacts, and the relay coil is triggered by a signal which is dependent on a specific speed of the internal combustion engine or a voltage of the generator.

10. Cooling system according to any one of claims 1 to 7 wherein a temperature sensor is provided in the form of a thermistor which is connected to the non-inverting input

of a second operational amplifier via a potential divider and the output of which is connected to the non-inverting input of the first operation amplifier.

11. Cooling system according to claim 10, wherein the thermistor is connected in parallel to the switch contacts.

12. Cooling system according to claim 10, wherein the thermistor is in series with one of the switch contacts.

13. Cooling system according to any one of the preceding claims, wherein the temperature differences between two successive switching thresholds are variable, the difference between the higher temperature switching thresholds being smaller than that between lower temperature switch steps.

14. Cooling system according to any one of claims 1 to 11, wherein the temperature differences between each pair of adjacent switching thresholds are equal.

15. Cooling systems according to any one of the preceding claims, wherein at least the power semiconductor and the operational amplifier or amplifiers are assembled to form a modular unit and this unit is arranged directly on the electric motor, that is on the side of the motor remote from the fan.

16. Method of controlling a cooling system according to claim 1, wherein switch contacts are closed successively by means of the temperature-sensitive sensor when preset switching thresholds are reached, whereby the input parameter is varied at a non-inverting input of an operational amplifier and its output level is varied, and that as a result of the varied output level of the operational amplifier, the power semiconductor is

triggered in such a manner that the electric motor is operated at specific speeds associated with steps of the respective switching threshold, and the power semiconductor is bridged when the last switch contact is closed.

17. Method according to claim 14, wherein a signal for exciting a relay is generated when the idling speed of the internal combustion engine is reached, the relay closes a relay contact and thus influences the input parameter of the operational amplifier in such a manner that the power semiconductor is triggered by a pulse train which corresponds to a relative duty factor of the power semiconductor with which the electric motor is operated at a minimum speed.

18. Method according to claim 16, wherein regulation of the speed of the electric motor, which is proportional depending on the cooling water temperature, occurs until a first temperature threshold is reached.

19. Method according to claim 16, wherein regulation of the speed of the electric motor, which is proportional depending on the cooling water temperature, occurs after a first temperature threshold is exceeded and until a second temperature threshold is reached.

20. Cooling system for an internal combustion engine, comprising a heat exchanger, a cooling water pump and a cooling fan for conveying the cooling air through the heat exchanger and also an electric motor for driving the fan or cooling water pump, substantially as described herein with reference to and as illustrated in the accompanying drawings.

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